THE DEFENSE NUCLEAR AGENCY INTERMEDIATE DOSE PROGRAM: AN OVERVIEW (EFFECTS OF TOTAL-BODY IRRADIATION ON THE PERFORMANCE OF PERSONNEL IN ARMY COMBAT CREWS)

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ABSTRACT

The objective of this research was to provide the quantitative basis for predicting performance decrement in Army crewmen irradiated with less than 4500 rads (cGy). Since the data necessary for these predictions do not exist and cannot be obtained directly by human testing due to the deadly nature of ionizing radiations, this effort involved not only the collection of data, but the development of a methodology to indirectly obtain the data. The data were obtained using a questionnaire derived from detailed information on radiation sickness and analysis of 15 combat crew tasks. The questionnaire, which asked for quantitative information on the impact of radiation sickness symptoms on the performance of sub-tasks, was administered to experts in the performance of the combat tasks. The results obtained in this effort clearly demonstrate that this methodology can be used to obtain meaningful estimates of the impact of very hazardous environments on performance. Comparison of the results from this study with those from studies which have directly assessed the effects of sickness on performance suggests that this questionnaire approach could successfully be applied to the evaluation of other hazardous environments in other military systems.

INTRODUCTION

The objective of this research effort was to provide the quantitative basis for predicting the performance decrement in Army infantry crewmen irradiated with less than 4500 rads (cGy). Army analysis of critical factors on the tactical battlefield indicates that nuclear radiation is the predominate casualty producing effect for nuclear weapons of 50 Kt or less. Present senerios for combat operations in a nuclear environment indicate that between one-half and three-quarters of the infantry personnel targeted with a tactical nuclear weapon would receive an initial radiation dose of greater than 150 rads (cGY) but less than 3000 rads (CGy). While, in general, the effects of radiation in this dose range are known, the precise effects of radiation on combat performance are not well known, especially the effects of radiation sickness. The present combat casualty criteria are based on the incapacitating and

killing effects of radiation derived primarily from animal experimental studies. Since no data exists with which to quantify degradation in performance from radiation sickness, these effects are not presently defined in the combat casualty criteria. While it is generally known that most of the individuals who receive more than the "Emergency Risk Dose" of 150 rads (cGy) but less than a "Latent Lethal Dose" of 650 rads (cGy), will experience radiation sickness, it is not known how radiation sickness will affect combat capability, despite the probable survival of many of these individuals. Since there is no way to directly test the performance of combat personnel in an actual or simulated radiation environment, obtaining data for these predictions is a major obstacle to accurate tactical nuclear planning.

The direct prediction of combat capability after a nuclear burst is not possible since there is no history of combat operations in a nuclear environment. In fact, there are very limited sources of information on the effects of prompt total-body irradiation—namely Hiroshima/Nagasaki, accidental expcsures, clinical irradiations, and animal experiments. In none of these cases except the animal experiments was task performace measured after irradiation. There are no performance measures which can be reconstructed from Hiroshima and Nagasaki. Additionally, uncertainties about the time at which radiation sickness occurred and the dose which individuals received limits the use of information which can be obtained from those bombings. Likewise, none of the accidental exposures produce any estimate of the effects of radiation on performance, except for the one case in which early transient incapacitation was. documented in the postirradiation clinical description (Shipman, et al., 1961). Only two studies (Payne, et al., 1963; Wolfgang and Maier, 1972) which have conducted as follow-ups to clinical irradiations have measured any aspect of psychomotor performance capability. Both of these studies employed severely ill cancer patients and neither employed performance measures which could be directly related to military task performance. Postirradiation performance has been measured in numerous animal experiments. This source of data provides good quantification for postirradiation incapacitation but much less information on the impact on performance of radiation sickness. Given the limitations on existing sources of data and the unacceptability of human testing to directly measure these effects, an indirect method had to be established to obtain measures of intermediate doses of ionizing radiation on combat performance.

APPROACH

A combination of several methods was employed in this project. The basic approach was to administer a questionnaire to senior crewmen in Army combat crews in order to obtain quantifiable judgements on the effects of radiation sickness upon the performance of their tasks. The questionnaire employed behaviorally anchored rating scales to obtain estimates of the impact of the symptoms of radiation sickness on the performance of

sub-task elements of Army combat crew functions. Prerequisite to the development and administration of the questionnaire was a detailed description of both radiation sickness Army crew functions. Subsequent to questionnaire administration were the multivariate analysis of the data, efforts to corroborate the results, and the development of a method to qunatitavively generalize to the data to the entire time-dose matrix. The discrete major elements which comprised this project were: (1) generating quantitative descriptions of radiation sickness, (2) developing behaviorally anchored scales of radiation sickness, (3) combining radiation sickness scales to produce "typical" symptoms complexes of illness syndromes, (4) combining radiation sickness syndromes and task analyses into a questionnaire, (5) administering the questionnaire, (6) applying a multivarate analysis to the results, (7) developing a quantitative method to generalyze the results to the entire time-dose matrix, (8) accounting for the psychological impact of nuclear combat, (9) integrating animal incapacitation data into the human performance decrement data, and (10) applying the analysis to Army planning. As such, this study was a multidisciplinary effort accomplished by several different organizations and guided by a working group.

The quantification of the signs and symptoms of radiation sickness during the first 6 weeks after exposure was undertaken as the first step in this project. To facilitate this process, the range of radiation doses between 75 and 4500 rads (cGy), free-in-air, was subdivided into 8 dose ranges associated with discrete pathophysiological events. For each subrange of dose, the "typical" incidence, severity, and duration of radiation sickness signs and symptoms were defined. These endpoints were quantified from the medical and research literature on human radiation sickness. This literature consists of (1) case studies of nuclear accidents, (2) records of patients given radiotherapy for cancer and other diseases, (3) analysis of "composite" studies, including the experience of the Japanese atomic bomb survivors, and (4) expert opinion. These data were analyzed by a working group of experts in radiobiology and radiation therapy to reach a consesus about "typical" symptoms.

In order to incorporate this radiation symptom information into behaviorally anchored rating scales for use in a questionnaire, the radiation symptoms information was divided into 6 separate categories of acute radiation symptoms. The symptom categories were: (1) upper gastrointestinal destress. (2) lower gastrointestinal distress, (3) fatiguability and weakness, (4) hypotension, (5) infection and bleeding, and (6) fluid loss and electrolyte imbalence. The symptoms for each of the categories of radiation-induced illness were described for mild to severe symptoms on a 5-point rating scale. Symptom complexes were then constructed, based on the severity descriptions for the 6 symptom categories and their occurance within the 8 radiation dose ranges. Since radiation sickness is manifest in a time-dependent manner, illness syndromes were simply a combination of symptom descriptions for each symptom category that occurred concurrently in time. From

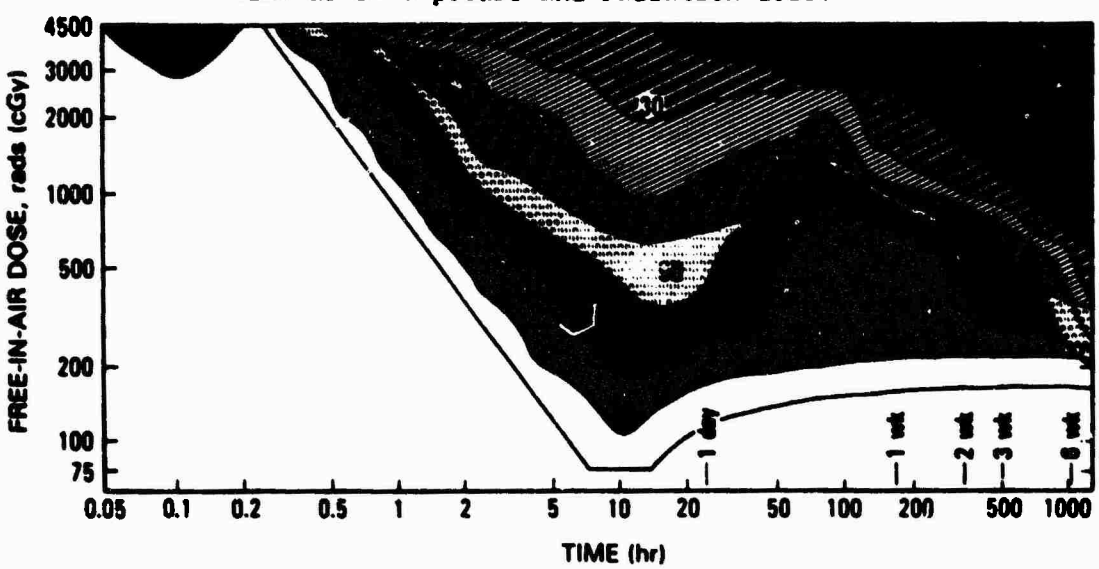
the large number of possible symptom complexes, the 30-40 unique syndromes which provided the greatest coverage of the time-dose matrix were chosen. As such, syndromes ranged from mild symptoms from a single category to to severe symptoms from several categories.

Each item on the questionnaire was comprised of a radiation sickness syndrome and a task element from the crew functions being tested. Respondants were asked to estimate the time required to complete a subtask element under the conditions of illness specified in the question. The impact of radiation sickness on each crew position was assessed in this way for the M60A3 tank, 155 mm self-propelled howitzer and fire-direction center, and the improved TOW vehicle. A detailed description of the construction and administration of the questionnaire is reported by Winne, et al. (1984) elsewhere in this symposium. Likewise, the analysis of the data, and the resulting predictions of individual crew-member performance have been summarized by Anno et.al. (1984)

RESULTS

The data obtained from the questionnaire (Winne, et al., 1984) and the predicted effects on each crew position (Anno et al., 1984) indicate that the effects of radiation sickness are dependent on the physical demands of the task. This trend was tested across all observations using a 2-way ANOV to compare overall performance decrement for a crew positions with symptom severity. Newman-Keuls comparisons indicate that for all symptoms there is a significantly greater ($p<.01$) performance decrement for the physically demanding tasks (e.g., gun crew loader) than for the non-physically demanding tasks (e.g., fire direction center). Based on this finding, predicted performance decrement was divided into 30, 50, and 70 percent bands, with limits of each band determined by the decrement observed in the most and least affected task. This analysis, together with regions of no effect and incapacitation, are summarized in Figure 1.

Figure 1: Radiation-induced performance decrement as a function of time after exposure and radiation dose.



DISCUSSION

The results of this study clearly indicate that significant differences in the effect of radiation sickness on the performance of military tasks can be identified and quantified using a questionnaire. In order to determine whether these differences are representative of performance decrements which are observed in the actual performance of military personnel during illness, these results were compared with the performance measures taken on Naval and Coast Guard Personnel during seasickness (Wiker, et al., 1980). Matched for symptom complex and task, the results of the two studies agree. Likewise, the finding of this study agree with the findings in animal research that postirradiation performance decrement increases with task demand.

Two aspects of the effects of radiations on the battlefield were not directly addressed by the questionnaire study. These were the psychological aspects of nuclear combat and the transient incapacition which can be produced by radiation exposure. The psychological impact of nuclear combat on military effective is a very difficult problem unto itself. This study did not attempt to quantify the performance decrement from the psychological trauma of nuclear battle. We did, however, conduct a comprehensive review of what is known in this area, what the problems are and what potential impact they might have. That review will be summarized in another paper in this symposium (Sessions, 1984). Transient behavioral incapacitation after irradiation was quantified from behavioral studies with monkeys. Too little data on incapacitation in man exists to permit a time and dose dependent description of its occurrance. Since this particular reaction is independent of the signs and symptoms of radiation sickness and has been carefully studied in monkeys, the primate data were used to quantify that aspect of the behavioral impact of prompt total-body irradiation. Taken together, these various sources of data present a comprehensive picture of the impact of radiation on the combat performance capability in Army crews. As such, this work suggests that the utilization of this type of questionnaire approach can provide a signiifcant tool for gathering data on performance in hazardous environments.

REFERENCES

(Due to space limitations, references have been omitted from this edition of the paper. References are available upon request from Robert W. Young, Armed Forces Radiobiology Research Institute, Bethesda MD 20814.)